A Novel method to Detect and Evaluate Power Quality disturbances using Hilbert Phase Shifting and CORDIC Algorithm

A Thesis submitted in partial satisfaction of the prerequisites for the degree of

Bachelor of Technology
in
Electrical Engineering

Submitted by:

Deepak Bharadwaz Rentala
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Under the supervision of
Prof. Dipti Patra

Department of Electrical Engineering,

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Certificate of approval

This is to certify that the project entitled, **A Novel method to Detect and Evaluate Power Quality disturbances using Hilbert Phase Shifting and CORDIC Algorithm** being submitted by ***Mr. Deepak Bharadwaz Rentala and Ms. Mohana Das*** has been carried out under my supervision in partial fulfillment of the requirements for the Degree of **Bachelors of Technology (B. Tech)** in Electrical Engineering at National Institute of Technology Rourkela, and this work has not been submitted anywhere else before for any other academic degree/diploma.

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Rourkela- 769008

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The written work of this paper has been a standout amongst the most scholastic difficulties we have ever needed to face. Without the help, persistence, direction of the accompanying individuals this work might not have been possible. It is to them that we owe my deepest gratitude.

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We are thankful to our friends for their help and motivation from backstage all through the journey of my life till date.

Lastly, our work towards the completion of the degree wouldn't have been possible without my unsung supporters. They are the members of our family, our greatest asset of all. Without them and their support there is no way we would be standing here today. There is no way to repay them for their love. We want to thank to our parents and sisters. Words can never express our gratitude for our family.

Deepak Bharadwaz Rentala

Mohana Das

ABSTRACT

Power Quality (PQ) is an umbrella term that encompasses all the aspects connected with amplitude, phase and frequency of the voltage and current waveforms existing in a power circuit. Adverse Power quality environments refer to the transient conditions developing in the power circuit and eventually affecting the load and the source. Power Quality Monitoring refers to the task of detecting the disturbances in the system which leads to the deterioration of the Power Quality and the immediate execution of measures to compensate the same. The various disturbances that adversely affect the quality of power include voltage sags, voltage swells, voltage fluctuation, transient oscillations, harmonics and inter- harmonics. The work aims at finding a unified and comprehensive method to detect and evaluate each of the Power Quality disturbances. The detection is facilitated through the Hilbert Phase shifting mechanism and the same detection output is used for the accurate evaluation of the disturbances based on CORDIC Algorithm. The methods developed are hindered by the presence of Noise in the system; hence emphasis has been laid to suppress noise for the efficient working of the algorithm which bases its working on Hilbert's Phase shifting property. The noise suppression is basically achieved by employing Mathematical Morphological filters and applying them before the signal is subjected to the detection and evaluation algorithm. The evaluation is based purely on the phase determining property of CORDIC (Coordinate rotation digital computer) Algorithm. A suitable model has been determined to efficiently account all the disturbances.

C O N T E N T S

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

INTRODUCTION:

Electrical Power Quality is an ancient subject which deals with the corruption of the power supply in such a way that the loads are disrupted and the system characteristics are degraded. The main issues of power quality has generally been confined to short term phenomena particularly voltage flicker, momentary events and harmonics. Historically, the first recorded problem of power quality dates back to 1890, when transformers and rotating machinery were identified as the main source of waveform distortion. A further additional harmonic problem associated with generator waveform appeared in the form of excessive circulating currents between solidly grounded generators operated in parallel appeared around the early 1900's along with the harmonic interference in communication circuits.

At that time, a reduction in harmonic distortion was achieved through a series of practices such as improved generator and transformer designs, improvement in grounding methods and the use of suitable three phase transformer connections. In 1960's, there were many individual shunt capacitors employed for reactive power compensation in industrial systems without much concern for harmonic resonance problems. This apathy among power engineers began to change when significant resonance problems were encountered, the problem originating from the harmonics generated by static drives. With the introduction of power electronics devices in voltage and power control in various industries, increased harmonic content has been observed in the system.

To minimize or wear out the effects of the harmonics, various methods have been implemented which involved the use of various filters and techniques which filter out the harmonic components effectively. To filter out the harmonic components the calculation of the harmonic frequencies is the underlying ordeal that has been challenging the researchers' right from the outset of the work in this field. Various tools have been developed for the spectral analysis, starting from Fourier transforms which later evolved to Discrete Fourier Transforms (DFT) and Fast Fourier Transforms (FFT). Similarly many other transformation techniques like Hartley transform, Parkinson transform, Hilbert transform have been employed for finding out the frequency spectra and evaluating the characteristic frequencies and the magnitude of power quality disturbances, but a uniform technique which is suitable for all types of harmonics and is also apt for real time application is yet to be devised.

1.1 MOTIVATION

The pronounced use of Power electronic devices in Power circuits has led to the repeated occurrence of various disturbances which have been affecting the power quality on regular basis. LabVIEW environment provides with various tools that help to realize the transformations practically and henceforth the design of methods to detect and evaluate the disturbances on the Virtual Instrument platform would be a simplified yet effective task.

The project work devises a method which bases itself on Hilbert Transform (HT) to detect the disturbances, classify them and also find out their characteristic magnitudes for a complete analysis. The various disturbances include voltage sags, voltage swells, voltage fluctuation, transient oscillations, harmonics and inter- harmonics. The algorithm has made suitable to run in real time bearing effective functioning. From the same detection output, a suitable model has been designed to source out the error signal responsible for the power quality disturbances.

Hilbert Transform has been chosen for its phase shifting property, which enables the signals to remain in the same domain and hence it becomes easy to calculate the phases and magnitude effectively with the aid of little mathematical manipulations which are predominantly effective.

CORDIC algorithm has been employed to calculate the phase of the disturbance or error signal at every point sample, so as to facilitate the reconstruction of the error signal by finding the phase and magnitude of the error signal at every point.

1.2 LITERATURE SURVEY

Power Quality Monitoring has been a subject revered historically for poor quality in power would lead to damage of utilities and machines to a greater extent. To devise methods to monitor power, we have chosen LabVIEW platform for the demonstration of effective methods to monitor power in real-time. For the first time Chen Xihui, Zhang Yinhong provided LabVIEW [4] utility and devised methods for analysis of power quality in Virtual Instruments and highlighted the ease of facilitation of this platform. Later Hu Qian, TANG Zhen-zou designed the primitive virtual instrument for analysis of harmonics through simulated signals on LabVIEW[5] platform. Then the design of the first online power quality monitoring system to analyse power in real time using DAQ cards on LabVIEW has been initiated which has formed basis for heavy research in this direction. Integrating the above researches the aim of our project is to design comprehensive virtual instrument, suitable for real time applications capable of detecting and evaluating effectively all the disturbances encountered in a network. For achieving the same, various transform techniques have been conisdered and a ready algorithm using one of the properties of Hilbert Transform has been developed for detecting and evaluating the disturbances.

The drawback of the method developed is the presence of noise, which has been hindrance to many of the classical methods developed in the past. Hence this aspect has to be suppressed and to achieve the same, noise supressing filters have been thoroughly studied. [7] Yue Wei and Liu Pei provided the first mathematical morphological filters and developments have been made over it. The Opening and Closing operation have been considered independently till date, with the introduction of [8] Margos filter, the complex operation of Opening- Closing and Closing-Opening have been organized to give the value of original Signal.

The evaluation scheme majorly bases itself on the CORDIC Algorithm which evaluates the phase of the signal at every sample and hence calculates the amplitude by assuming a sinusoidal model of the disturbance signal. The advantage of such signal is that all the disturbances can be accounted and can be evaluated accurately in real time. J. E. Volder[10] designed the algorithm in early 1960's. Subsequently the applications of CORDIC have become dominant in the field of Signal Processing.

1.3 OBJECTIVES

The work aims at finding a unified method to detect, classify and evaluate all the Power Quality disturbances in the real time. To aid the same, a combination of two different concepts has been employed to accurately evaluate the disturbances. The phase shifting property of Hilbert Transform has been employed in the initial stages; this has been sufficiently supported by CORDIC Algorithm which helps in accurately evaluating the phase of the disturbance signal. The algorithm has been observed to be staggering when fed by a signal corrupted by noise; hence a smoothing operation has been done on the input signal, prior to feeding it to the algorithm. Hence all these factors accounted, the Power Quality disturbances are detected and evaluated accurately.

1.4 THESIS ORGANIZATION

Chapter 1 – Introduction

The history of Power Quality monitoring, right from the time when the term was coined to the present day is looked into and the motivation behind choosing this topic and the prospective research has been discussed.

Chapter 2 – Detection of Disturbances using Hilbert's Phase shift

Various disturbances in Power Quality have been elucidated. The fundamental principles of Hilbert Transform has been discussed. The utility of the property of Phase shifting and its significance in the method has been described. The simulation results and the execution of the method on simulated disturbances and satisfying results have been shown.

Chapter 3 –Noise suppression through morphological Filters

The algorithm used requires noise suppression or completely noise free signals for its effective functioning, hence mathematical morphological filters have been studied and have been presented in detail.

Chapter 4 – Evaluation through CORDIC Algorithm

The transforms relating to the algorithm, the working principle based on CORDIC algorithm and accurate evaluation of Power Quality disturbances has been presented.

Chapter 5 – Results and Futurework

The overall work, the results and future prospects of work has been discussed in this particular section.

CHAPTER 2

Hilbert Phase-Shifting Detection Scheme for Various PQ Disturbances

2.1 Introduction

The major disturbances in Power quality comprise of voltage sags, voltage swells, voltage fluctuation, transient oscillations, harmonics and inter- harmonics. The typical detection methods are based on time domain methods or frequency domain methods making them suitable to detect only a particular type of disturbance at a given instant. The proposed method of application of phase shifting property of Hilbert transform is inherently a steady inter-convertible from time and frequency domain making it a flexible technique for the detection of disturbances of a wide range with uncharacteristic properties. The method even provides with the time of occurrence of the disturbance making it suitable for real time application. Coupling the method with feasible LabVIEW platform and executing it has given satisfactory results

2.2 Insight into Various Power Quality Disturbances:

The various types of PQ disturbances have been illustrated in the following sections

2.2.1 Voltage Sag:

A voltage sag otherwise known as voltage dip is a short duration fall in RMS voltage which can be caused by short circuit, overloading or starting of electric motors. Voltage sag is recognized when the RMS voltage falls between 10 to 90 percent of nominal voltage for one-half cycle for duration of one minute. Some references define sag's duration for a period of 0.5 cycles to a few seconds, and duration longer than that would be called "sustained sag". The sag is defined by the equation:

$$u(t) = 1 \pm (\mu(t - t_1) - \mu(t - t_2))) \sin(\omega t)$$

Where $\mu(t)$ is a unit step function.

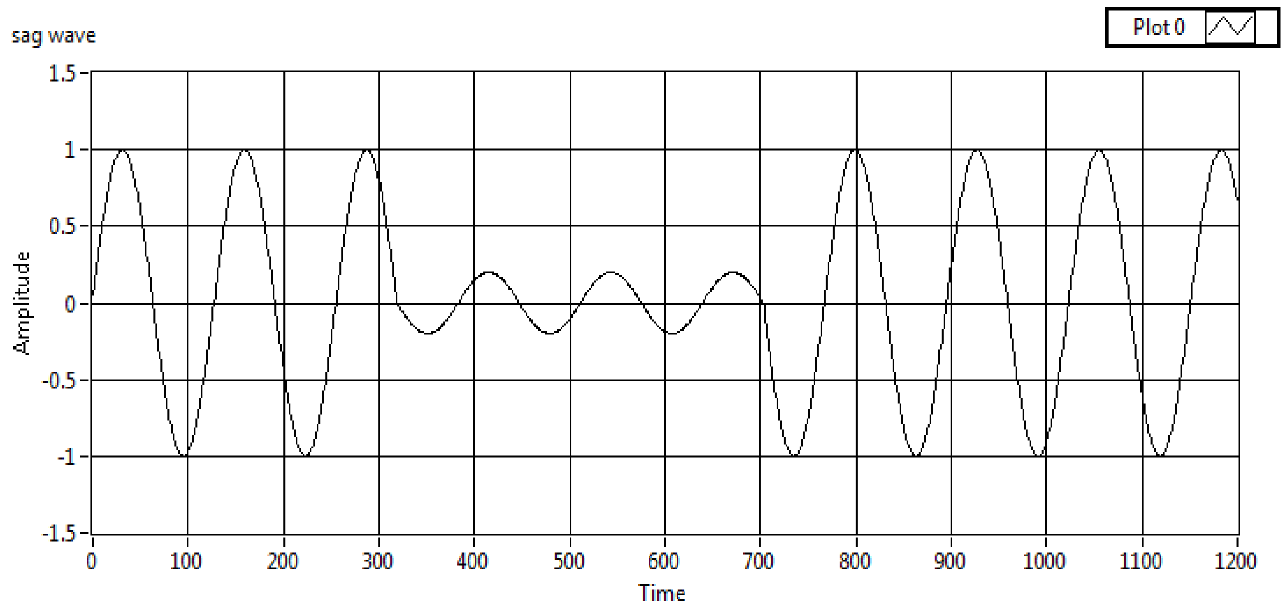

Fig. 1. Simulated Sag wave with sag amplitude 0.2

The Sag wave generated is 0.2 times the original amplitude, the sag is effectively observed between the interval 350 to 720 samples.

2.2.2 Voltage Swell

Voltage Swell is the opposite of Voltage sag, where the voltage momentarily rises above the regulated voltage value, for a short duration of time. Voltage swell is also characterized by:

$$u(t) = 1 \pm (\mu(t - t_1) - \mu(t - t_2))) \sin(\omega t)$$

Here the raise in the voltage is obtained by taking the functions in a negative way by negative time.

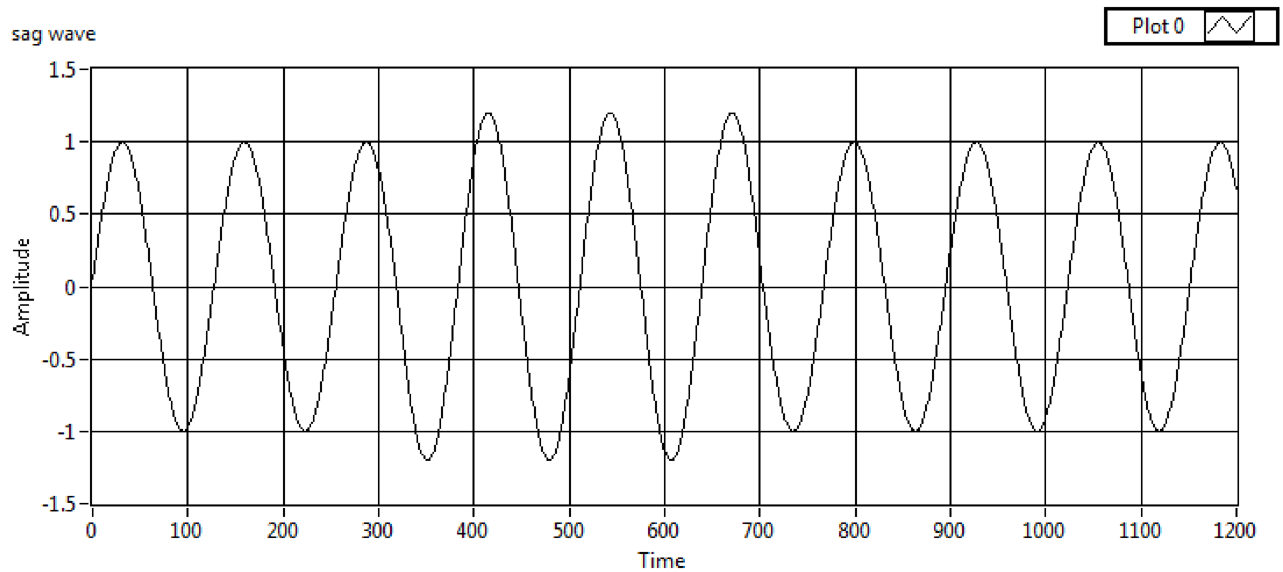

Fig. 2. Simulated Swell wave with swell amplitude 1.2

The Swell wave simulated has an amplitude which is 1.2 times the normal wave. The swell is observed between the intervals 400 to 700 samples effectively which is shown in the Figure

2.2.3 Momentary Interruption

Momentary interruption means that a signal is interrupted during that time interval, i.e., signal is zero during that time interval. Momentary Interruption has been elucidated in the Figure 3

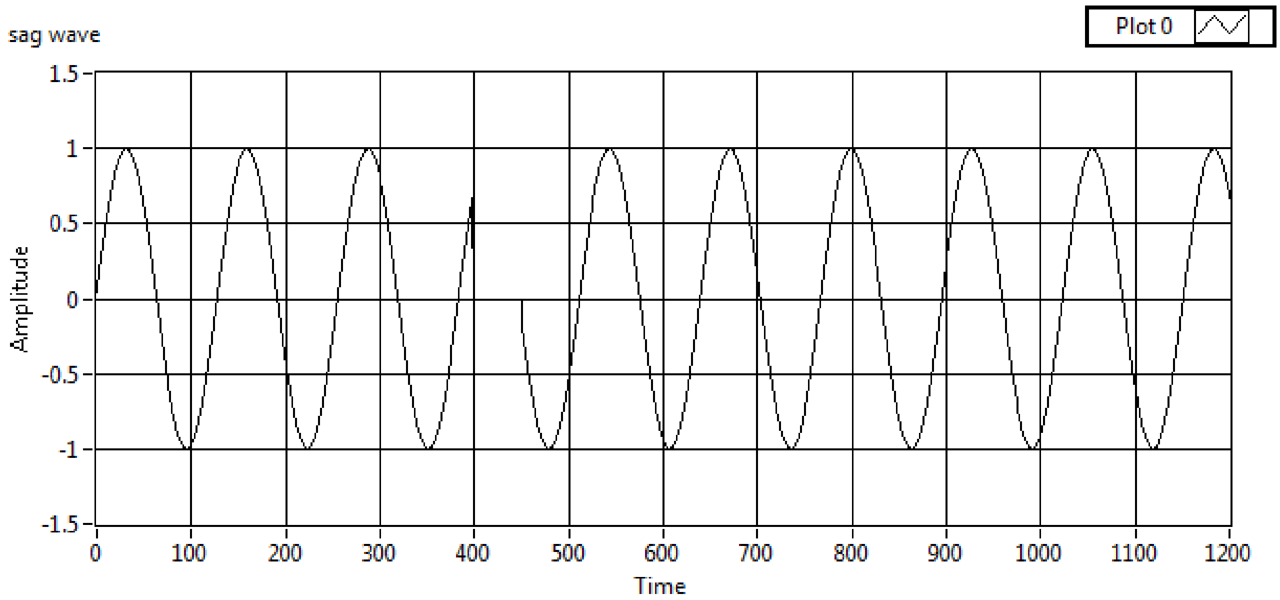

Fig. 3. Momentary interruption occurring at 400 samples

2.2.4 Flicker

Flickers occur due to momentary outages of voltages at particular instants of time, they might not pose long term problems but lead to the generation of harmonics if not checked for. The characterstics of flickers has been shown in Figure 4 at instants 398,408,416 samples.

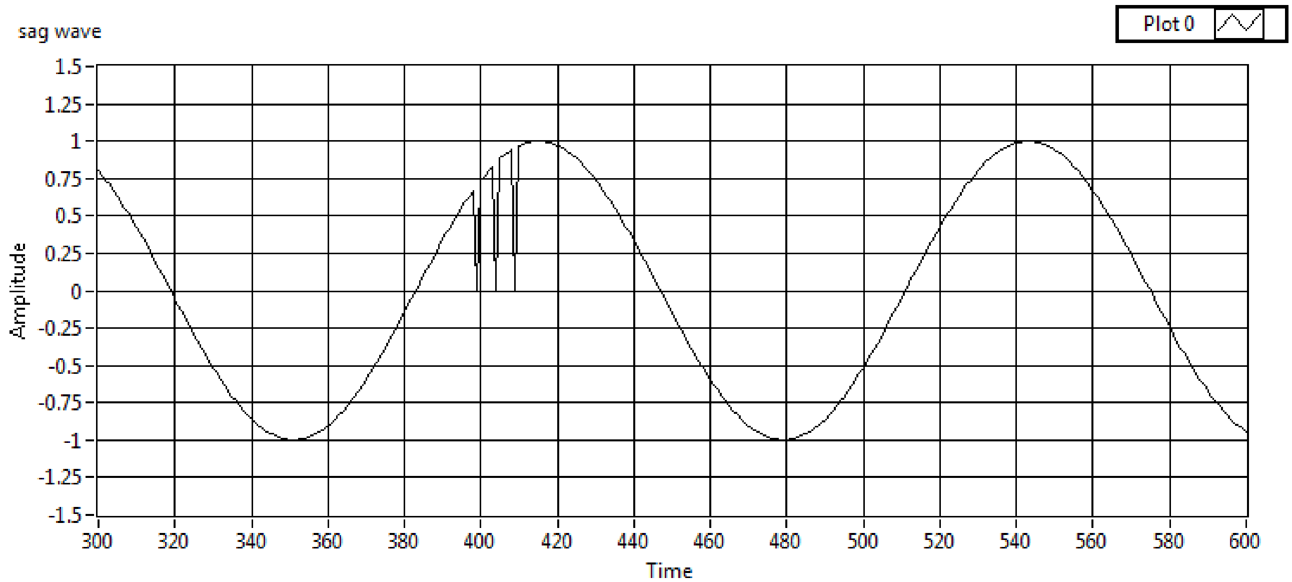

Fig. 4. Flickers occurring around 400 samples

2.2.5 Harmonics:

A harmonic of a wave is an integral multiple of the fundamental frequency, i.e. if the fundamental frequency is *f*, the harmonics frequencies are *2f, 3f, 4f,* . . . etc. The harmonics contribute to bulk of the problems in PQ monitoring and hamper the Power Quality considerably. Detecting and mitigating harmonics is the bulk of the task in Power Quality monitoring. A distorted harmonic waveform is created by adding 3rd, 5th, 7th and 9th harmonics to the ideal waveform. The equation for harmonics, where the respective alphas are characterstic magnitudes.

$$u(t) = \sin(\omega t) + \alpha_3 \sin(3\omega t) + \alpha_5 \sin(5\omega t) + \alpha_7 \sin(7\omega t)$$

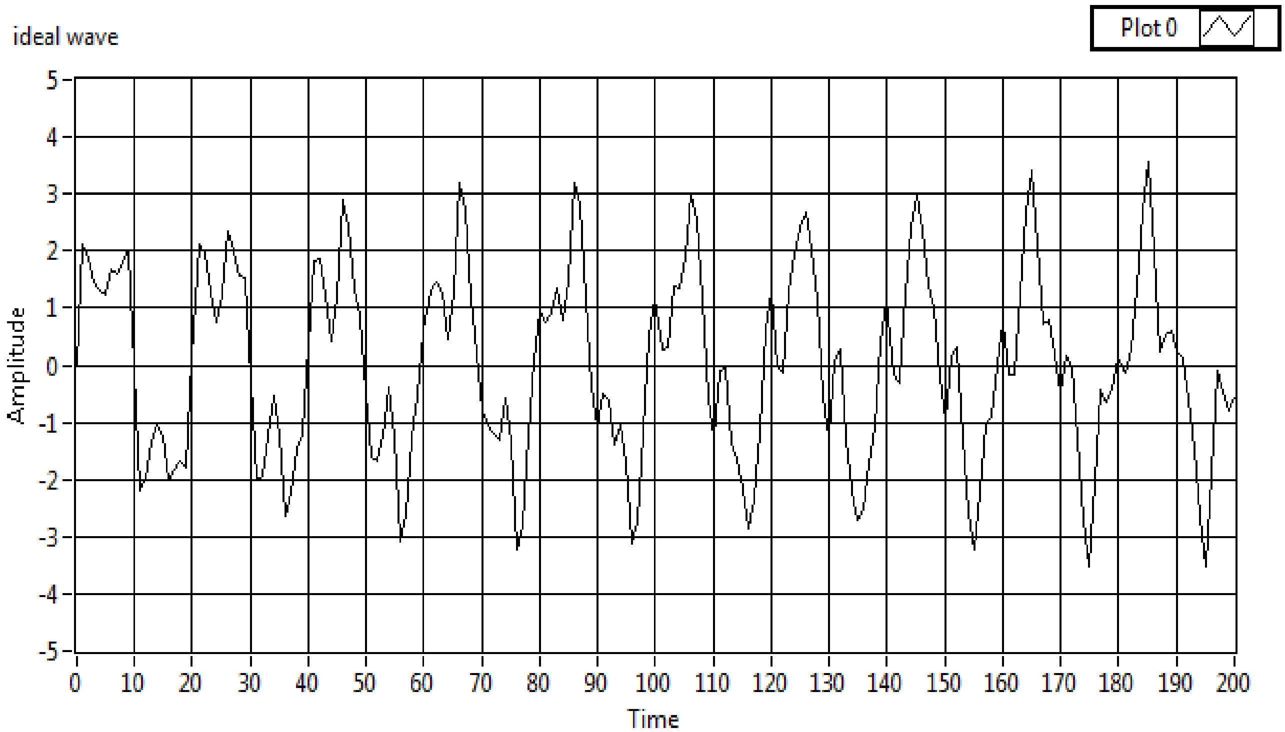

Fig. 5. Fundamental wave with harmonic components

2.3 Basic principle of the Hilbert Transform (HT):

The HT of a function is characterized as the convolution between the functions x(t) and h(t) =1/πt. The expression for the same is

$$H[x(t)] = x^h(t) = x(t) * h(t) = x(t) * \frac{1}{\pi t} = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{x(\tau)}{t-\tau}\, d\tau$$

In the formula, * represent convolution operator; $H[x(t)]$ and $x^h(t)$ represent HT in time-domain and the operator in time domain respectively. Unlike other transform techniques, the HT of time-domain function is still in time domain, the HT in frequency domain can be portrayed as

$$X^h(f) = X(f).H(f)$$

Because the FT of h(t) $\mathrm{F[h(t)] = H(f) = -jsgn(f)}$

=-j 1 if f>0

-1 if f<0 sgn is the sign function

So we can obtain HT on frequency- domain, if we multiply the negative frequency part of X(f) by j and multiply positive frequency part of the X(f) by $-j$.The HT result can be expressed from FT, So

$$x^h(t) = x(t) * h(t) = F^{-1}[X(f).H(f)\ ]$$

As input signal $\mathrm{x(t) = \ sin(2\pi ft)}$, its FT is:

$X(f) = \frac{j}{2}\,[\delta(f + f_i) - \ \delta(f - f_i)$, now multiplying the negative frequency of the $X(f)$ by j and multiplying positive frequency of the $X(f)$ by

$$X^h(f) = \frac{1}{2}\,[-\delta(f + f_i) - \ \delta(f - f_i)] = F[-\cos(2\pi f_i t)]$$

Taking Fourier inverse to both sides of the formula, we get

$$Hsin(2\pi f_i t) = \ -cost(2\pi f_i t)$$

Formula shows negative of cosine function results by HT of the sine function, the result also depicts that it contributes to –j phase- shift of the input signal. The HT of an input cosine signal is the sine function, showing that it makes –j phase- shift to the input signal too. So the HT can provide 90° phase-shift and not influence the amplitude of the input wave component.

2.4 Detection of Disturbances using Hilbert's Phase shift

The ideal signal of power system is a pure sinusoidal waveform

$$u(t) = A\sin(2\pi f t + \emptyset) = A\sin(\omega t + \emptyset)$$

In formula: A is the amplitude of the voltage; f_0 is the fundamental frequency: 50Hz; $\emptyset_0$ is the initial phase of the system.

In ideal conditions, the properties of u(t) are :

$$u^2(t) + u^2(t - \pi/2) = [A\sin(\omega t + \emptyset)]^2 + [A\sin(\omega(t - \frac{\pi}{2}) + \emptyset)]^2 = A^2$$

Then the detection output y(t) would be :

$$y(t) = u^2(t) + u^2(t - \pi/2) - A^2$$

Hence if input signal is the ideal sinusoidal waveform, the detected output $y(t)$ is zero. However when the input signal has characterstic disturbances, the expression for input signal is:

$$u(t) = A\sin(\omega t + \emptyset) + e(t)$$

After 90° phase- shifting to the u(t):

$$u_2(t) = u\left(t - \frac{\pi}{2}\right) = A\sin(\omega t + \emptyset - 90) + e(t - 90)$$

So, $$y(t) = \varepsilon(e(t))$$

So when the disturbances contained in the input signal are predominant, the detection output certainly cannot be equal to zero. The disturbance $\mathrm{e(t)}$ will have different sets of values when the disturbances inputs are different and detection output will have different varied waveform characteristics, as it corresponds to the time when disturbances take place, it can assure the detection's real-time characteristic.

2.5 Results and Simulations:

The phase shifting algorithm has been applied to various power quality disturbances and the disturbances have been detected successfully. The following VI has been used as base VI for the simulation and detection, shown in Figure 6.

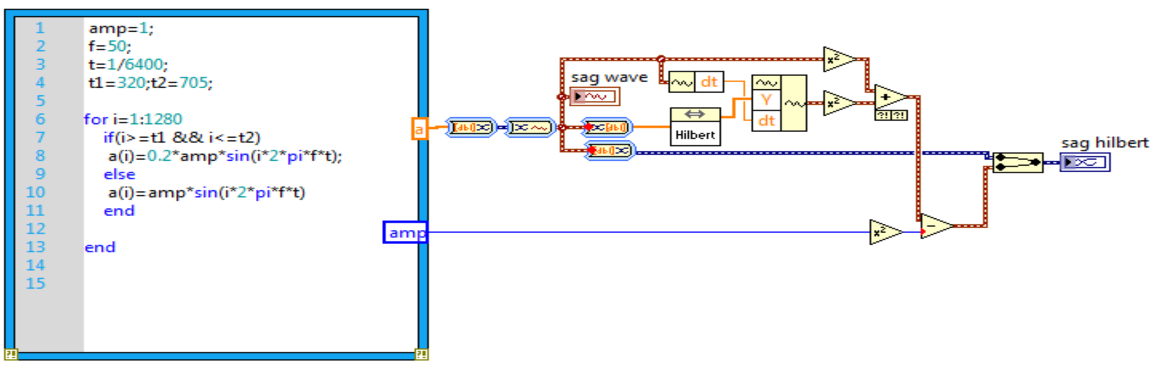

Fig. 6. Base VI for Hilbert Detection

2.5.1 Voltage Sag:

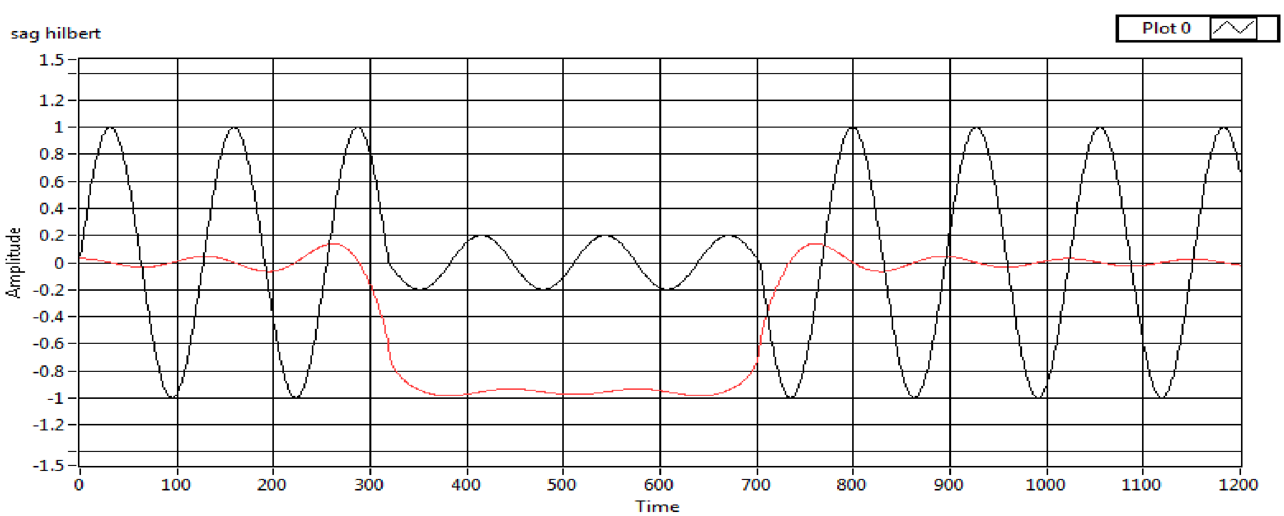

Fig. 7. Hilbert detection of Sag wave

2.5.2 Voltage Swell:

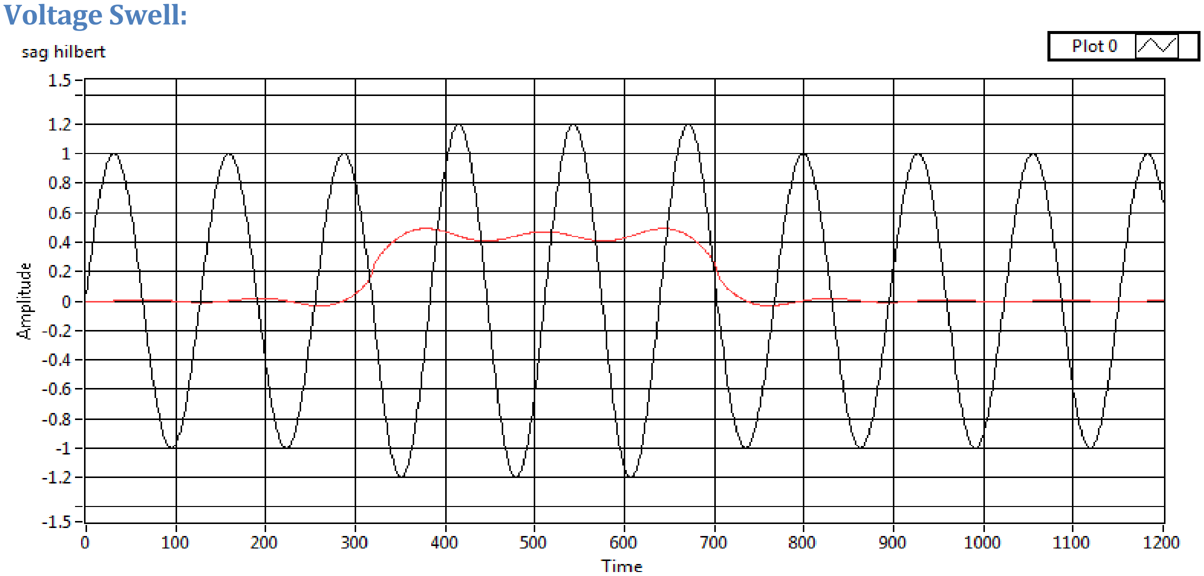

Fig. 8. Hilbert detection of Swell wave

2.5.3 Momentary interruption:

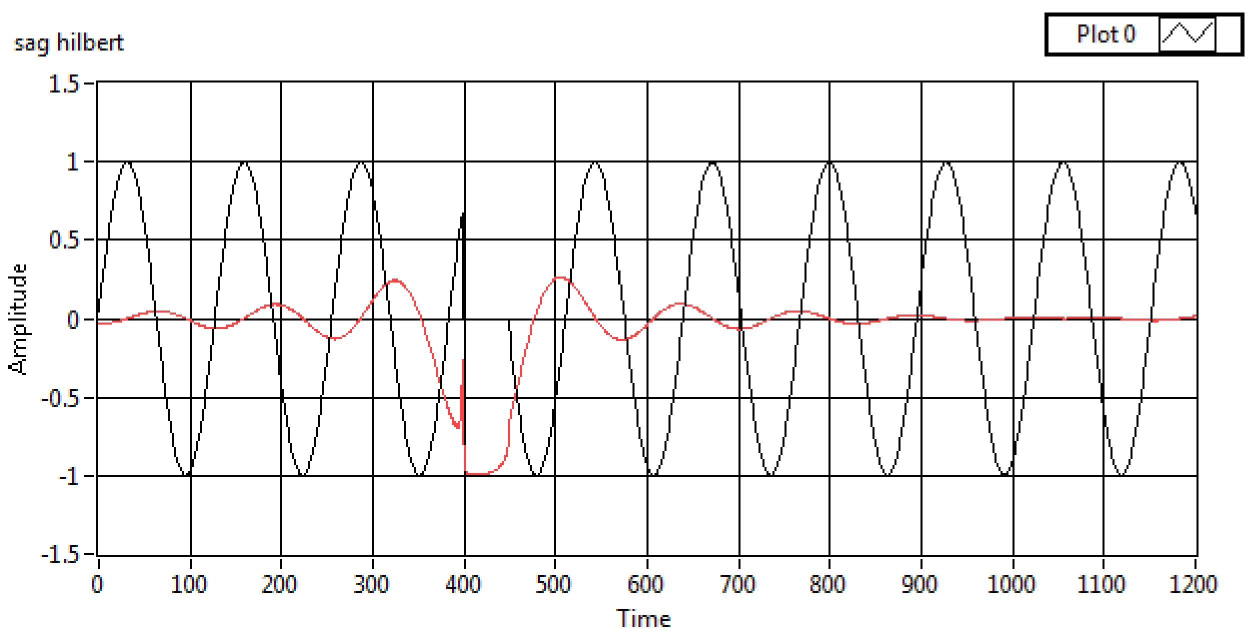

Fig. 9. Hilbert detection of Momentary Interruption

2.5.4 Voltage Flicker:

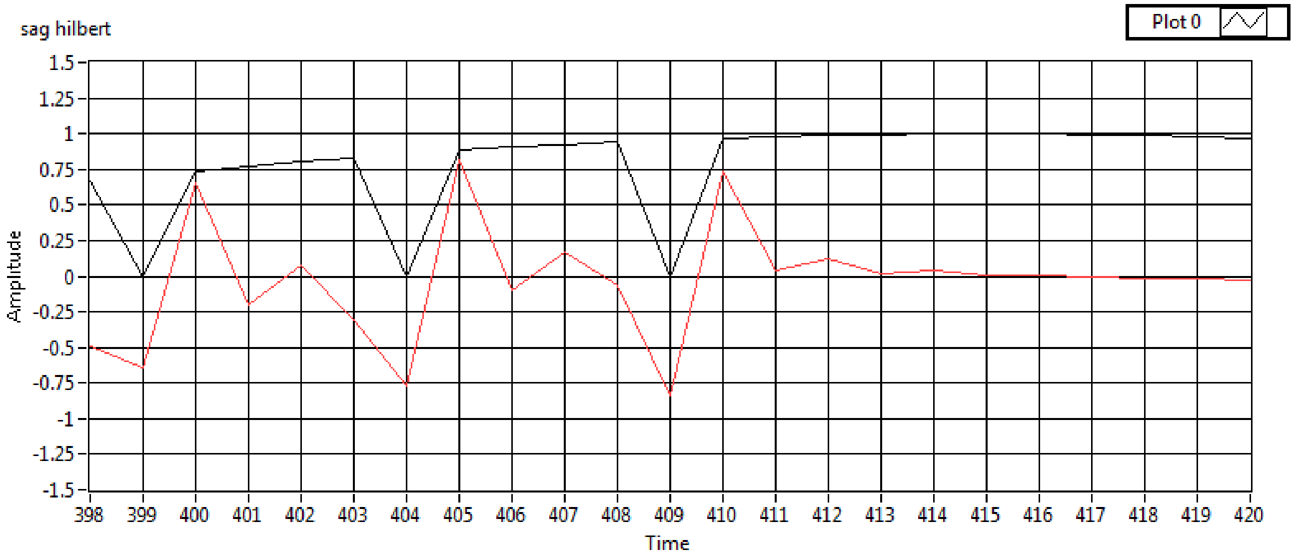

Fig. 10. Hilbert detection of Voltage Flicker

2.5.5 Harmonics:

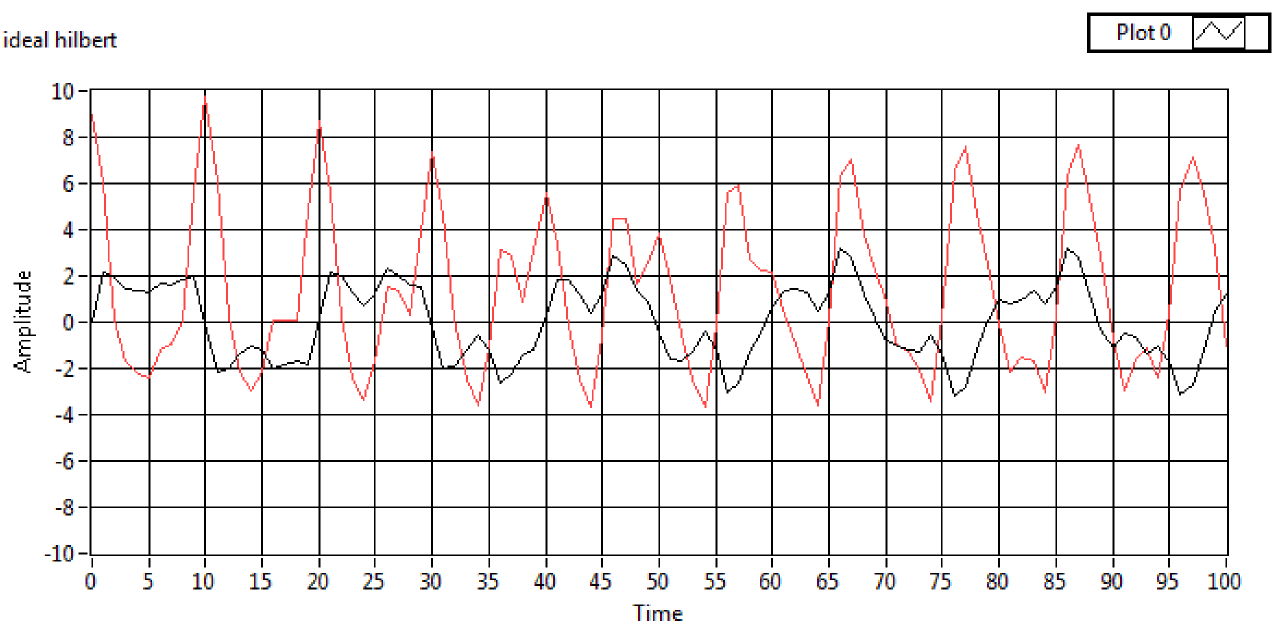

Fig. 11. Hilbert detection of Harmonics

CHAPTER 3

Noise Suppression Using Mathematical Morphological Filters

3.1 Introduction

The Hilbert detection Algorithm devised may not work efficiently under the influence of noise present in the system. Hence the noises arising in the system are studied discreetly in this chapter and a smoothing filter which is basically a mathematical morphological filter, has been employed to deal with the same. These filters are employed to smooth out the signal, make it noise free even before the signal is fed to the algorithm.

3.2 Types of Noises:

Uniform White Noise: White noise is nothing but a random arbitrary signal with power spectral density remaining constant. The term also represents a signal with samples that are a sequence of uncorrelated random variables which have finite variance and zero mean.

Gaussian White Noise: Gaussian noise is nothing but statistical noise whose probability density function (PDF) is equivalent to that of normal distribution or the Gaussian distribution. A special case of the same is white Gaussian noise, in which the values at any two instants of times are identical and statistically independent.

Periodic Random Noise: Periodic Random Noise (PRN) is the sum of sinusoidal signals with the exactly same amplitudes but phase being a random one. PRN does not possess energy for all frequencies like Gaussian white noise. However, PRN has vitality just at in a far-reaching way discrete frequencies that compare to key harmonics; then again, the level of noise at each of the discrete frequencies is the same

3.3 Introduction to Morphology:

The essential concept is to utilize a probe, which is named as Structuring element, to gather data of the signals. As the SE moving in the signal always, it can audit the interrelation around every part, and get helpful data to break down and portray the indicators. Erosion, dilation, opening, closing and the compound opening and closing are the operations essential to construct a compound filter. Suppose that the definition domain of the input signal f(n) and the structuring element g(n) is F={0,1,…,N-1} and G={0,1,…,M-1}, respectively, and N□M.

The dilation and erosion of f (n) by g (n) are defined as

$$(f\oplus g)(n) = \max[f(n-m)+g(m)]$$

$$(m= 0\sim M-1)$$

$$(f \ominus g)(n) = \min[f(n + m) - g(m)]$$

$$(m= 0\sim M-1)$$

The opening and closing are defined as

$$(f \circ g)(n) = (f \ominus g \oplus g)(n)$$

$$(f \blacksquare g)(n) = (f \oplus g \ominus g)(n)$$

The compound Opening and Closing Operations are defined as

$$f_{oc}(n) = (f \circ g \blacksquare g)(n)$$

$$f_{co}(n) = (f \blacksquare g \circ g)(n)$$

3.4 Morphological Filters:

The opening-closing and closing-opening filters have the essential features of opening and closing operation. So the average value of the two filters has been used to make these filters which approach the original very well. This filters are defined as

$$f_m(n) = (f_{oc}(n) + f_{co}(n))/2$$

3.5 Results and Simulations:

The Results have been demonstrated choosing all the noises for the first Power Quality disturbance and few of them the noises have been demonstrated in the other disturbances to elucidate the effectiveness of the algorithm.

3.5.1. Noise suppression in Ideal waveform

An ideal waveform is generated in LabVIEW of frequency 50 Hz, amplitude 1, sampling frequency 6400 Hz and number of samples 1280. A Gaussian white noise of standard deviation 0.1 and 1200 samples is added. The actual waveform is shown in Figure 12, the Noise free waveform is shown in Figure 13.

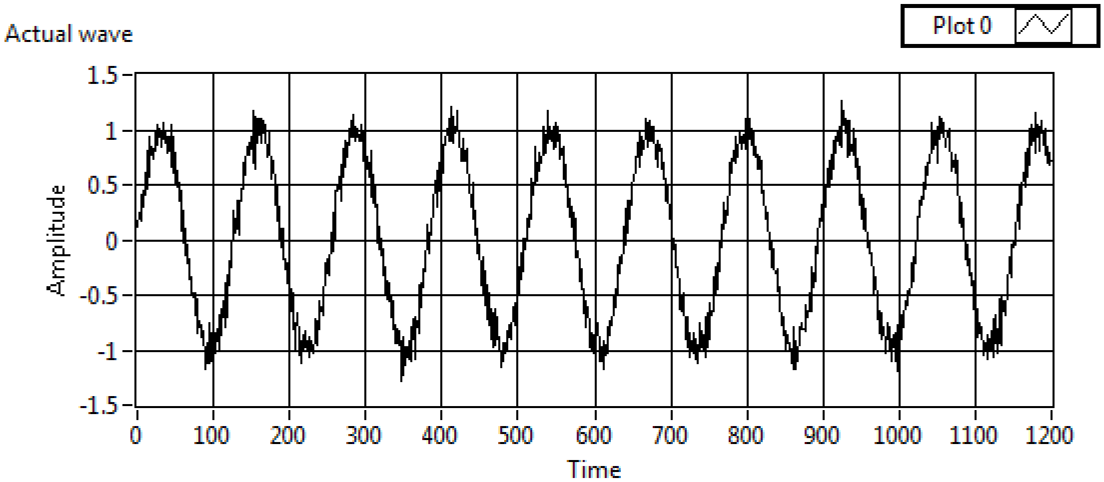

Figure 12: VI with noise added to Ideal waveform

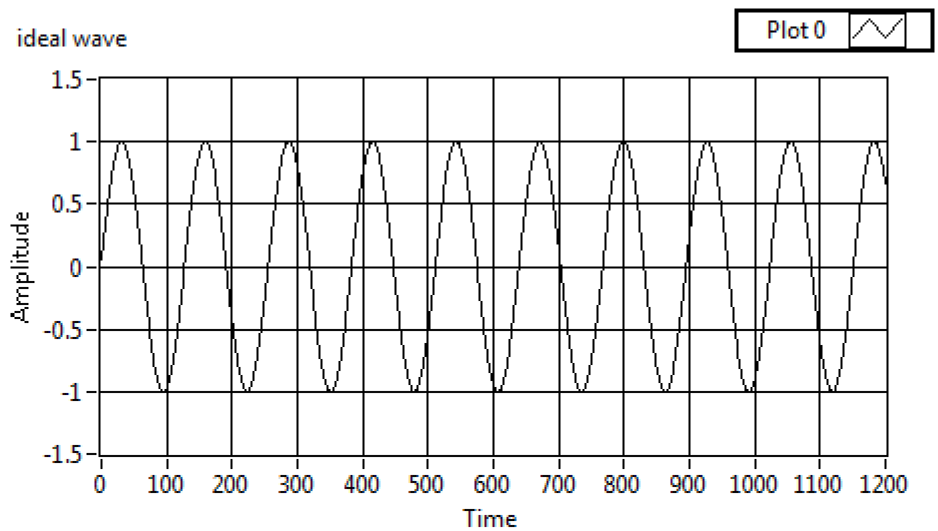

Figure 13: Noise Suppressed Ideal waveform

3.5.2 Voltage sags

A voltage sag signal of amplitude 0.2 times the normal amplitude during disturbance is generated and all the three types of noises are added and suppressed. Figure 14 shows the voltage sag with Uniform White Noise, Figure 15 shows the Gaussian White noise, Figure 16 shows the Periodic Random Noise. Figure 17 shows the Noise suppressed output which is same in all the cases. The number of samples chosen for this case is 1200.

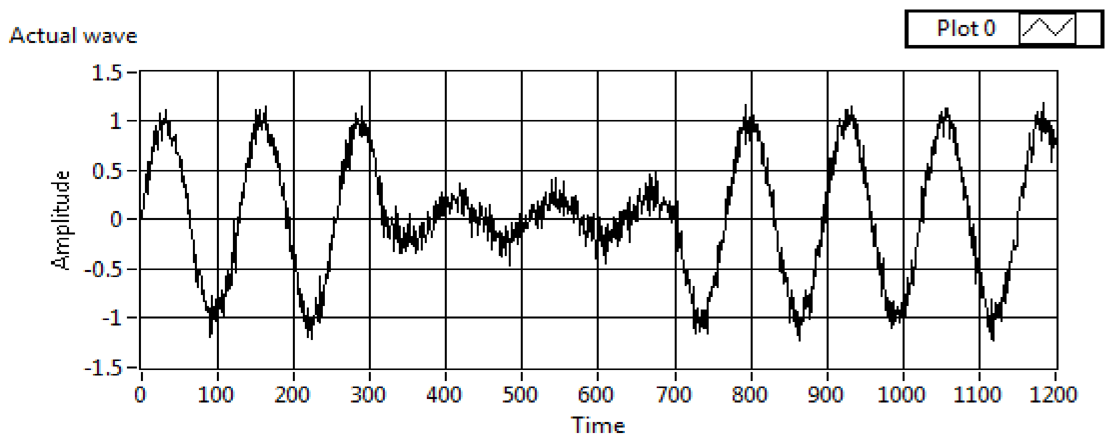

Figure 14: Sag Generation along with Uniform White noise

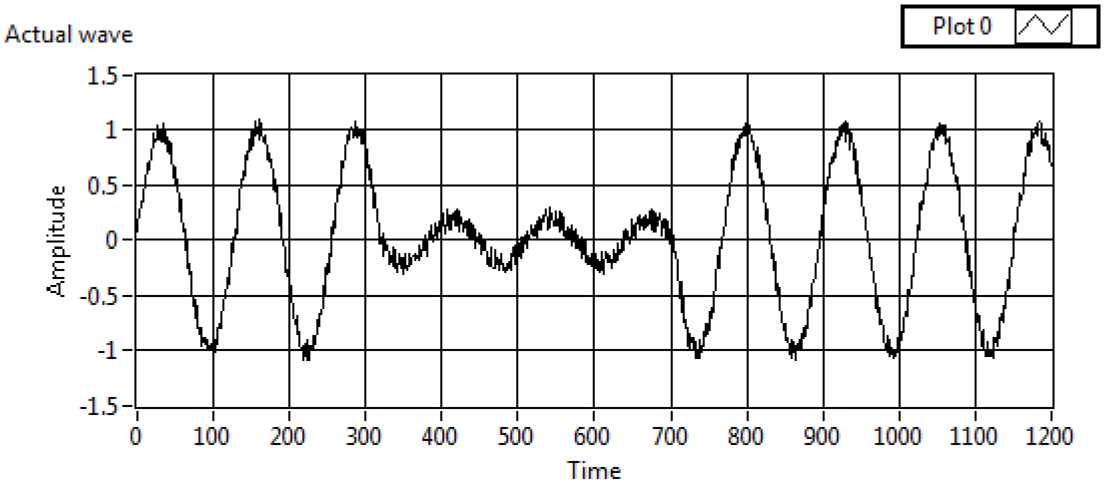

Figure 15: Sag Generation along with Gaussian White noise

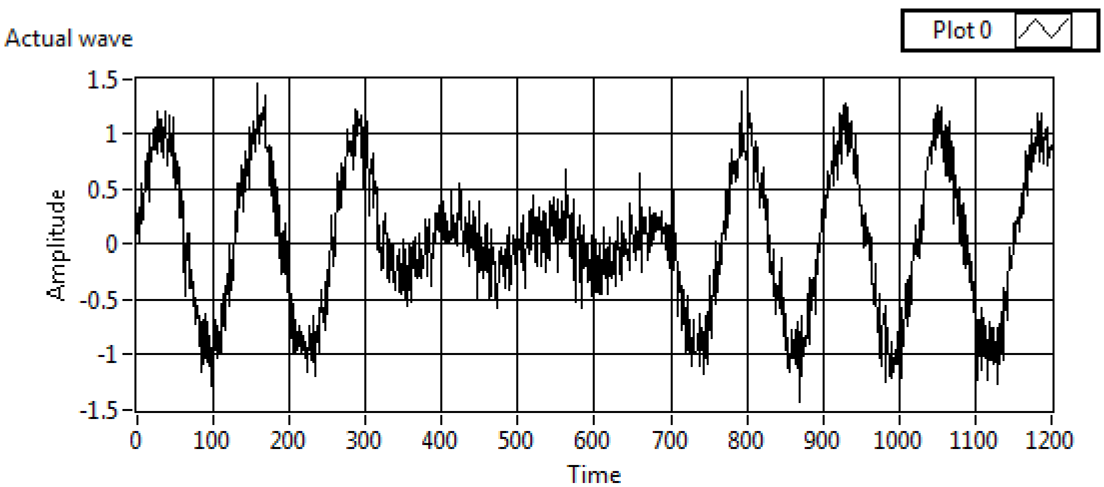

Figure 16: Sag Generation along with Periodic Random noise

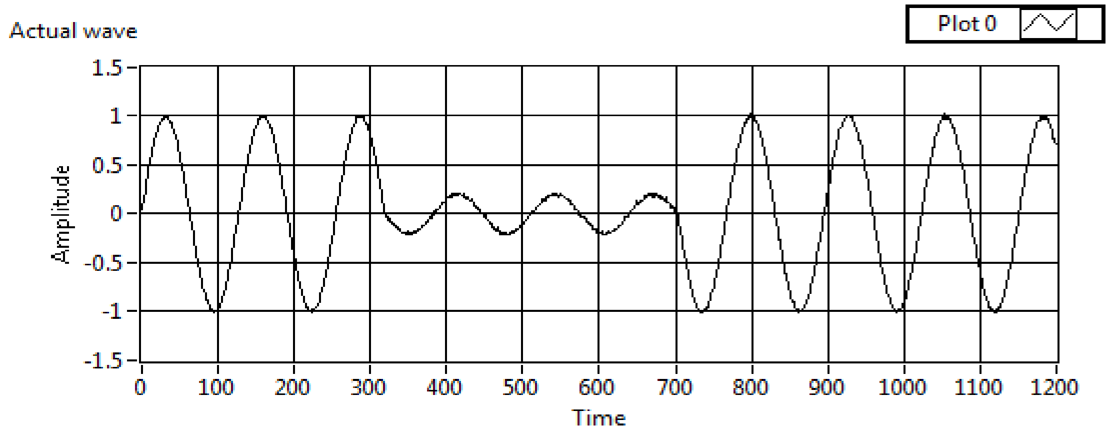

Figure 17: Noise Suppressed Sag wave

3.5.3 Voltage swells

A distorted waveform is generated with a swell between 320 and 700 seconds. The noise is shown predominantly in Figure 18. The noise suppressed waveform is shown in Figure 19.

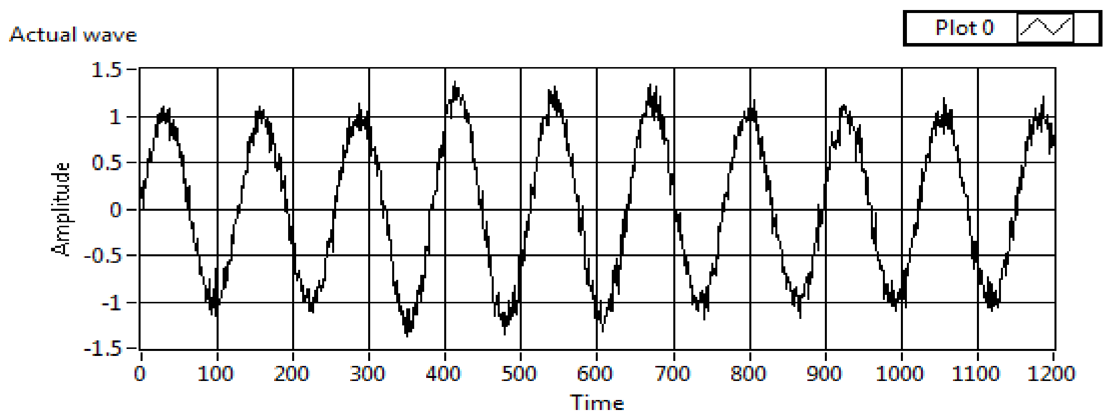

Figure 18: Swell Generation along with Gaussian White noise

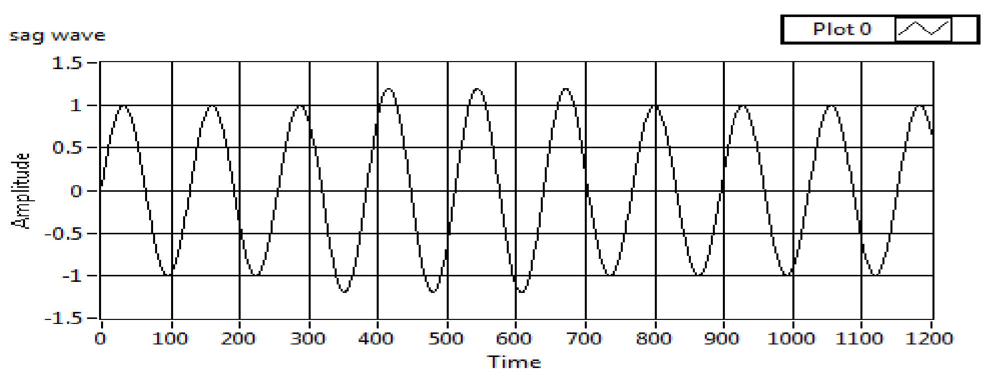

Figure 19: Noise free Swell generated wave.

3.5.4 Momentary Interruption

Momentary interruption means that a signal is interrupted during that time interval, i.e., signal is zero during that time interval. The same signal has been simulated with Noise and then suppressed as shown in Figure 20 and Figure 21.

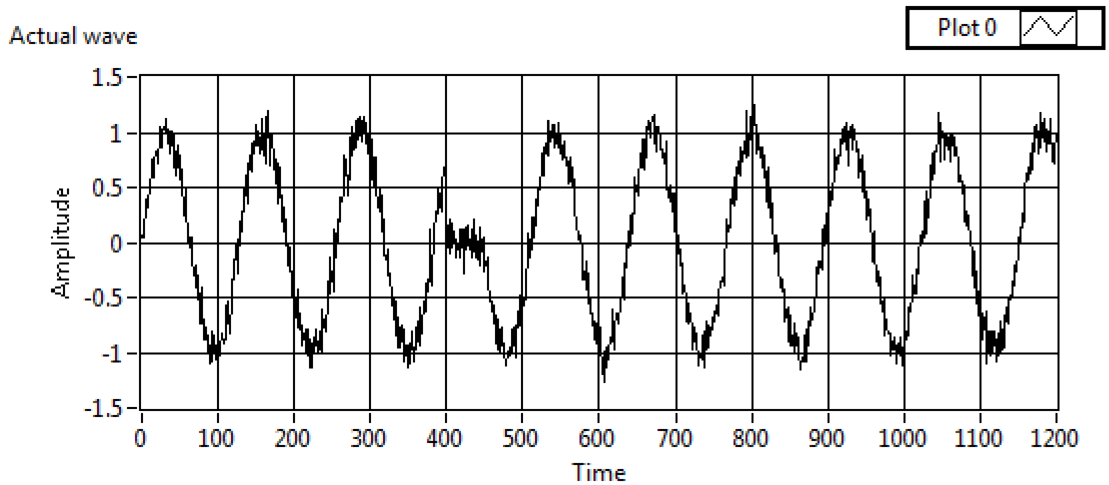

Figure 20: Momentary Interruption wave with noise.

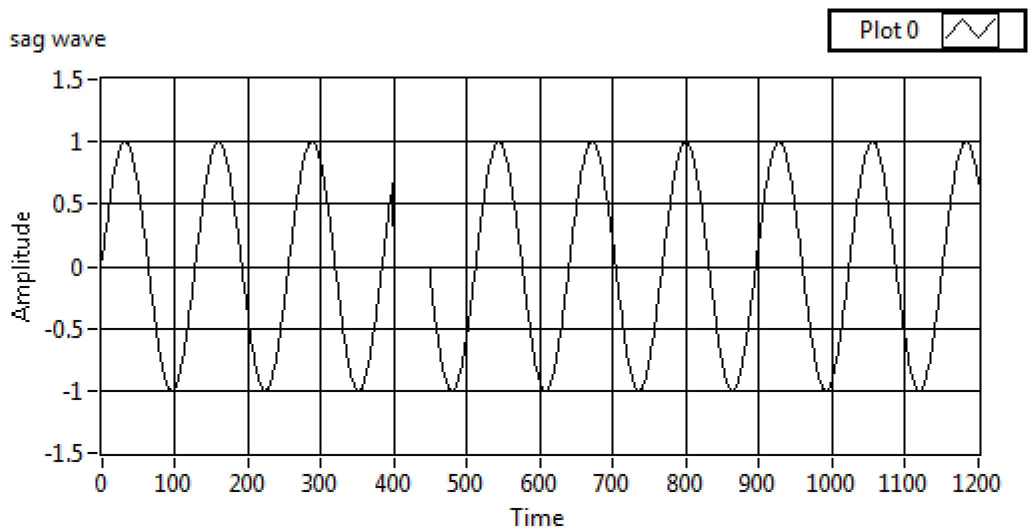

Figure 21: Momentary Interruption wave without noise.

3.5.5 Flickers

Flickering means the voltage momentary becomes zero after few instants, the Vi has been simulated by making the voltage zero at times t=399, t=404 and t= 409 along with Gaussian White noise.

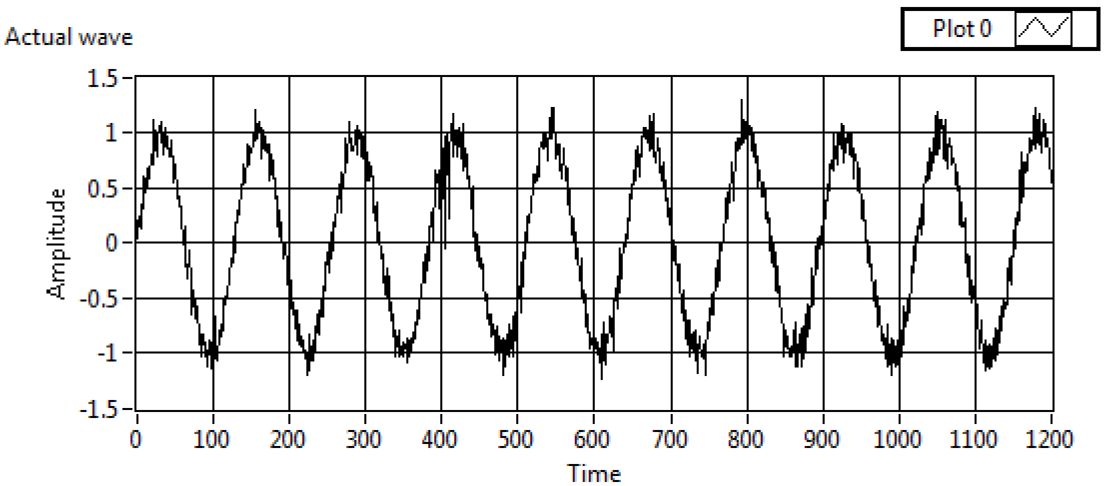

Figure 22: Voltage Flicker wave with noise.

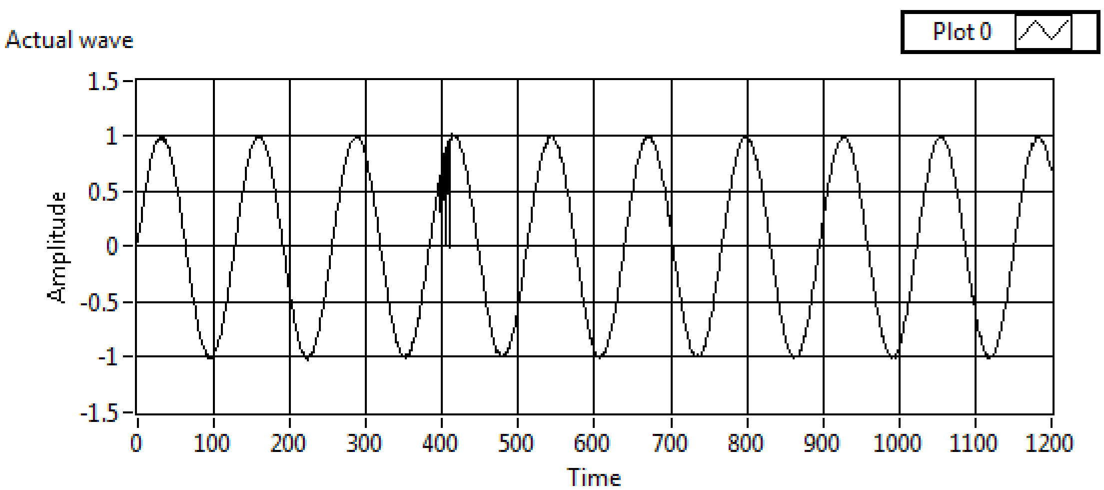

Figure 23: Voltage Flicker wave without noise

3.5.6 Harmonics

A distorted harmonic waveform is created by adding 3rd, 5th and 7th harmonics to the ideal waveform along with noise. Figure 24 depicts waveform with noise and harmonics. Figure 25 depicts the noise free waveform.

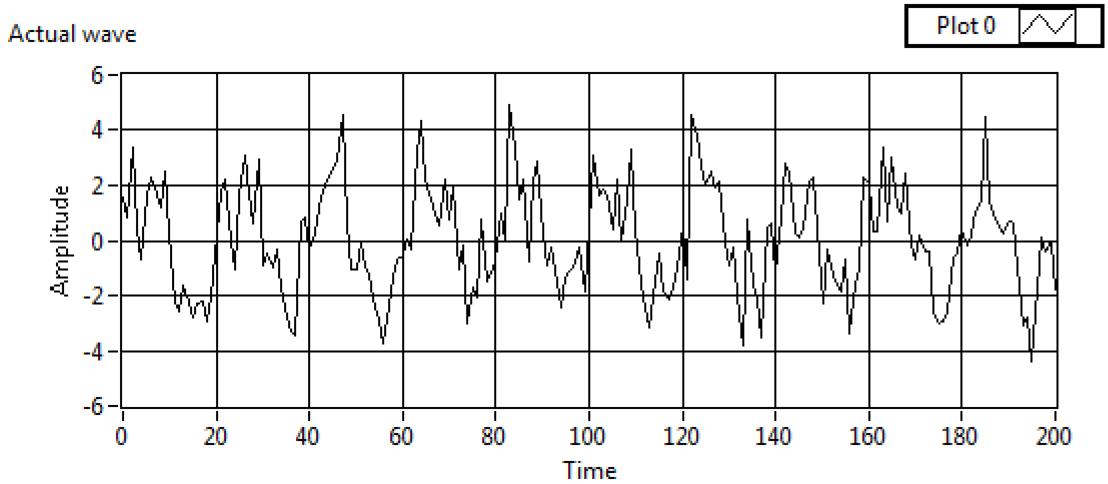

Figure 24: Harmonic wave with noise

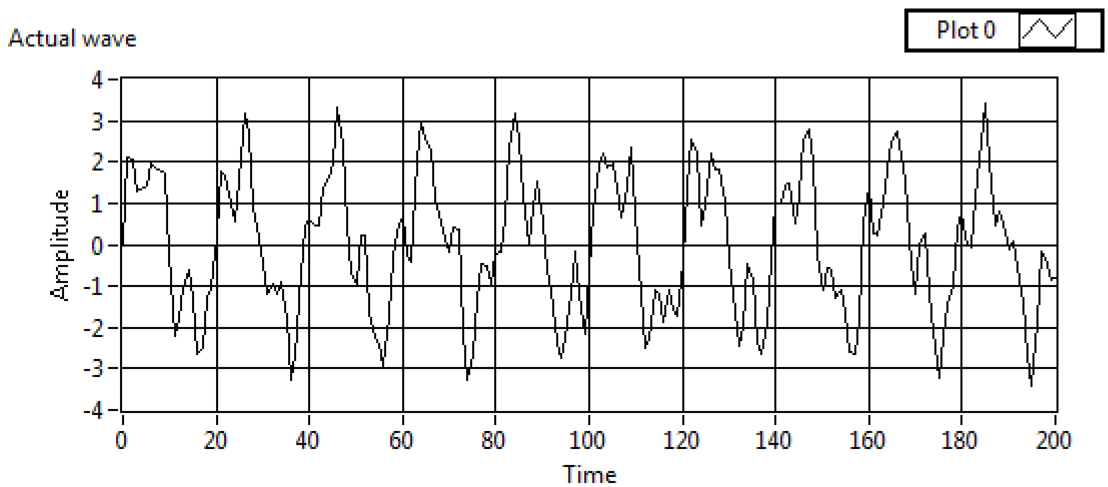

Figure 25: Harmonic wave without noise

CHAPTER 4

Evaluation of PQ Disturbances through CORDIC Phase Evaluation and Detection Algorithm.

4.1 Introduction:

The PQ disturbances are evaluated on the basis of the detection output of Hilbert Phase shifting. A suitable model is chosen for the same purpose. The modelling has been shown in the subsequent sections.

4.2 Evaluation of Power Quality disturbances:

For the purpose of evaluation, the error signal is chosen of the form

$$e(t) = A' \sin(\varphi)$$

The amplitude and phase of the error signal may vary invariably and hence account for all types of error signals. Evaluation of both amplitude and phase at every point yields the reconstruction of Error signal. For the evaluation of phase, CORDIC Algorithm is employed and the detection output is correspondingly used to evaluate the amplitude at every point.

Then the input signal is given by:

$$u(t) = A\sin(\omega t + \emptyset) + A'\sin(\varphi)$$

Since the reference input signal is known, the hypothetical form of the error signal is obtained by subtracting $A\sin(\omega t + \emptyset)$ from $u(t)$, the reference hypothetical error signal is given as

$$z(t) = A' \sin(\varphi)$$

By applying Hilbert transform to the hypothetical error signal, we get

$$H[z(t)] = A' \cos(\varphi)$$

The signals are combined to form an analytic function:

$$R(t) = A' \sin(\varphi) + jA' \cos(\varphi)$$

The phase of this analytic function is phase of the error signal at any point. Hence CORDIC algorithm is employed to find the phase of this analytic function which enables us to evaluate the signal at every point.

Applying the detection scheme and evaluation scheme with the current model:

$$u(t) = A\sin(\omega t + \emptyset) + A'\sin(\varphi)$$

Applying Hilbert Transform to the input signal:

$$H[u(t)] = A\cos(\omega t + \emptyset) + A'\cos(\varphi)$$

Applying the detection scheme we get:

$$y(t) = u(t)^2 + H[u(t)]^2 - A^2$$

$$= [A\sin(\omega t + \emptyset) + A'\sin(\varphi)]^2 + [A\cos(\omega t + \emptyset) + A'\cos(\varphi)]^2 - A^2$$

$$= A'^2 + 2AA'[\cos(\omega t + \emptyset - \varphi)]$$

The phase is obtained from the CORDIC algorithm and hence the amplitude can be calculated accordingly.

$$A' = -A\cos(\omega t + \emptyset - \varphi) + \sqrt{(A\cos(\omega t + \emptyset - \varphi))^2 + y(t)}$$

4.3 Introduction to CORDIC

CORDIC stands for COordinate Rotation DIgital Computer. It calculates the trigonometric functions, their magnitudes and phase (arctangent) to a desired precision and accuracy. CORDIC bases itself around the idea of "rotating" the phase of any given complex number, by multiplying a succession of constant values. The multiplier chosen is of the form $(1 \pm jk)$ where 'k' is of the form 2^{-L}, where 'L' takes the values 0,1,2,3,4….. Successively.

4.4 Phase computation using CORDIC Algorithm:

Consider the complex number whose phase is to be calculated. If it is of the form $(\mathrm{I} + \mathrm{jQ})$, the sign of the phase can be observed basing on the signs of I and Q. If the phase is positive, multiply the number by $1 - \mathrm{jk}$ and similarly if the phase is negative, multiply the number by $1 + j\mathrm{k}$. Note that the amount of phase multiplied to the number is $\pm\mathrm{atan}(k)$. Now by observation, determine the sign of the phase of the new number obtained and correspondingly multiply the number by $1 \pm j\mathrm{k}$ with successive values of 'k'. At every step note the amount of phase added/subtracted to the number. This is repeated until the number becomes purely real, that is the phase of the number becomes zero. At this point, all the phases calculated to this point are added with their signs and hence, the sum gives the accurate phase of the number under consideration.

Code for finding the Phase of the error signal:

Here the real part of the analytic function is the input 'x' and the imaginary part is the input 'y':

```
phasesum=0;
k=1;
while i != 0
{
a = x;
b=y;
phase=atan(y/x);
if phase>0
{
x=a+(k*y),y=b-(k*a),k=k/2;
}
elseif phase<0
{
x=a-(k*b),y=(k*a)+b,k=k/2;
}
phase=atan(y/x);
```

phasesum=phasesum+phase;

i=phase;

}

End

The output ‘Phasesum’ gives the output phase of the analytic function and hence the error signal.

4.5 Results:

The base VI for the evaluation scheme has been shown below:

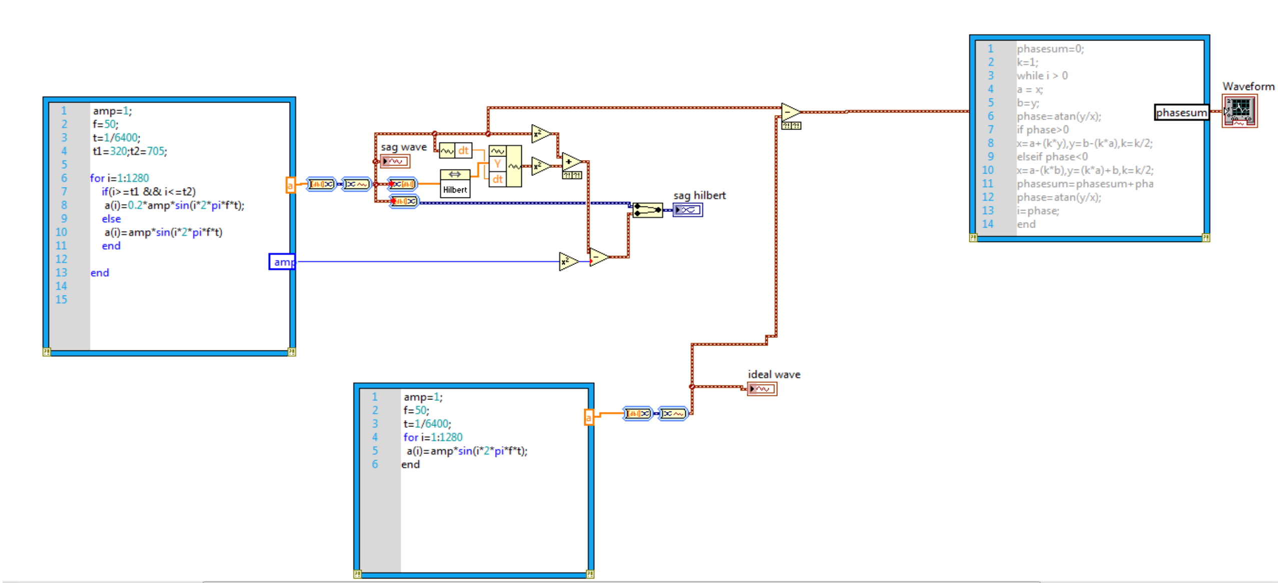

Figure 26: Base VI for evaluation scheme

4.5.1 Voltage Sag:

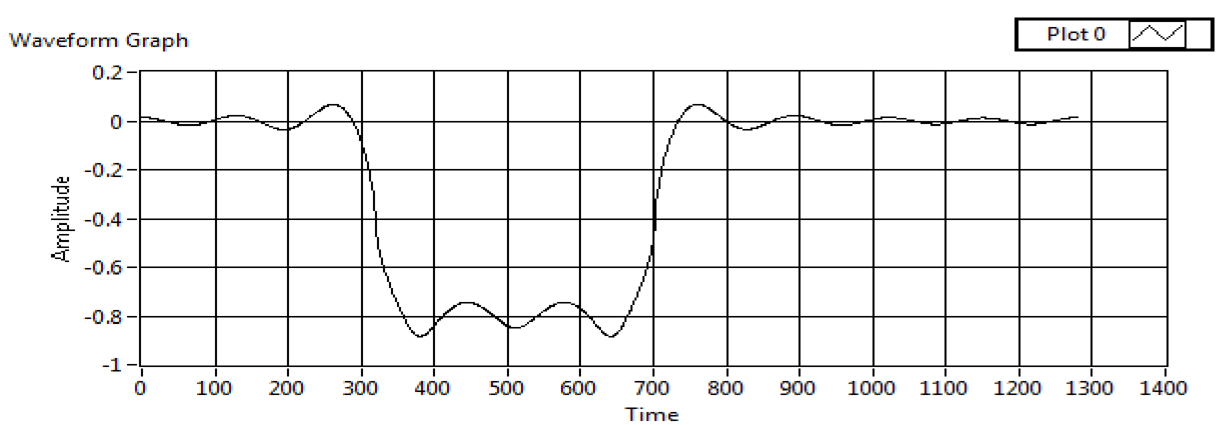

Figure 27: Evaluation of Sag

4.5.2 Voltage Swell:

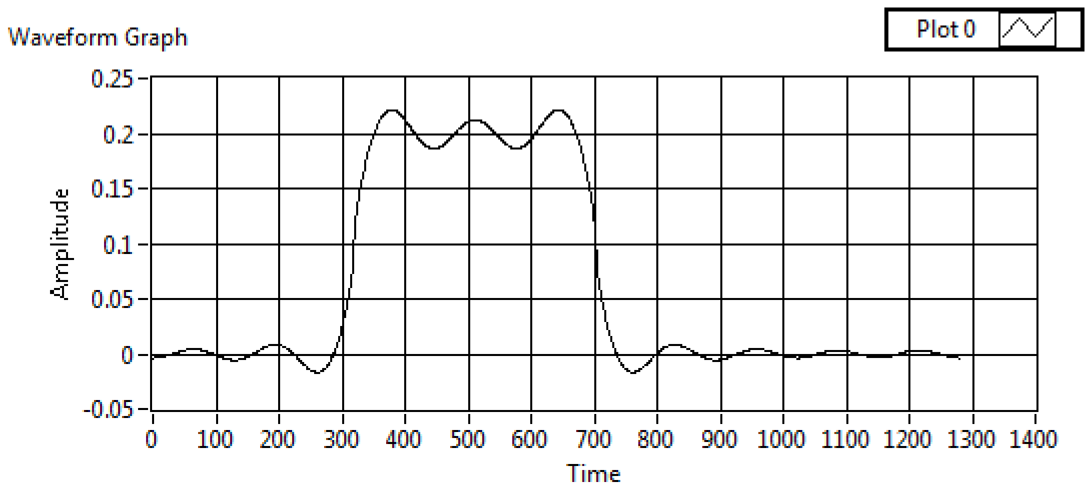

Figure 28: Evaluation of Swell

4.5.3 Momentary Interruption:

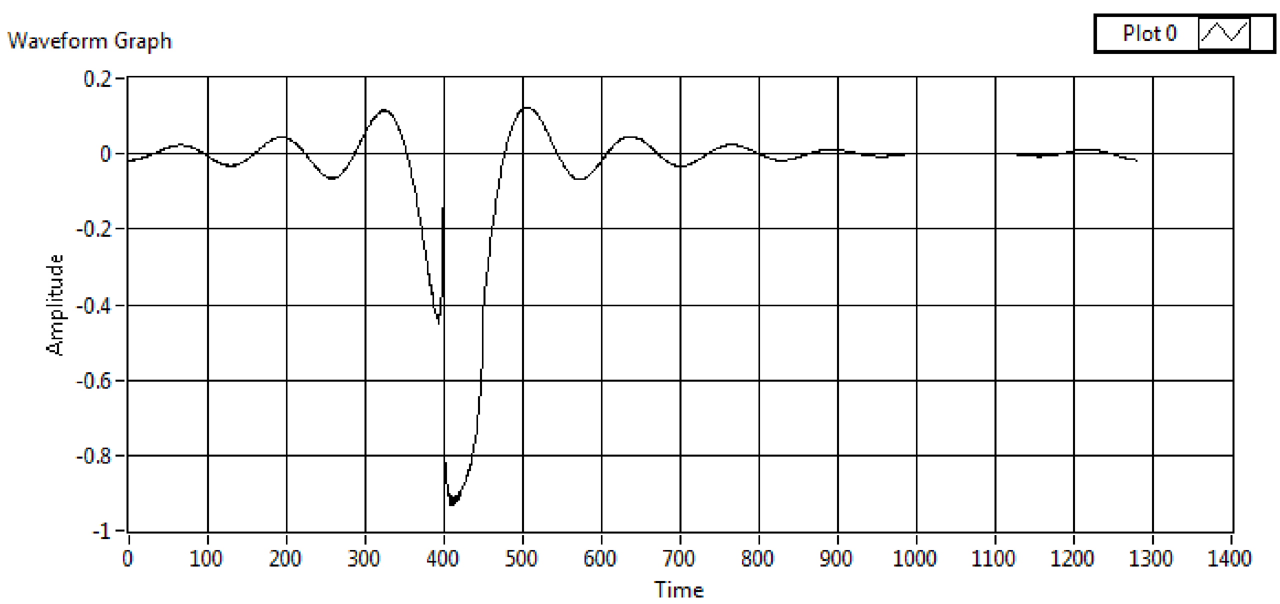

Figure 29: Evaluation of Momentary Interruption

4.5.4 Flicker:

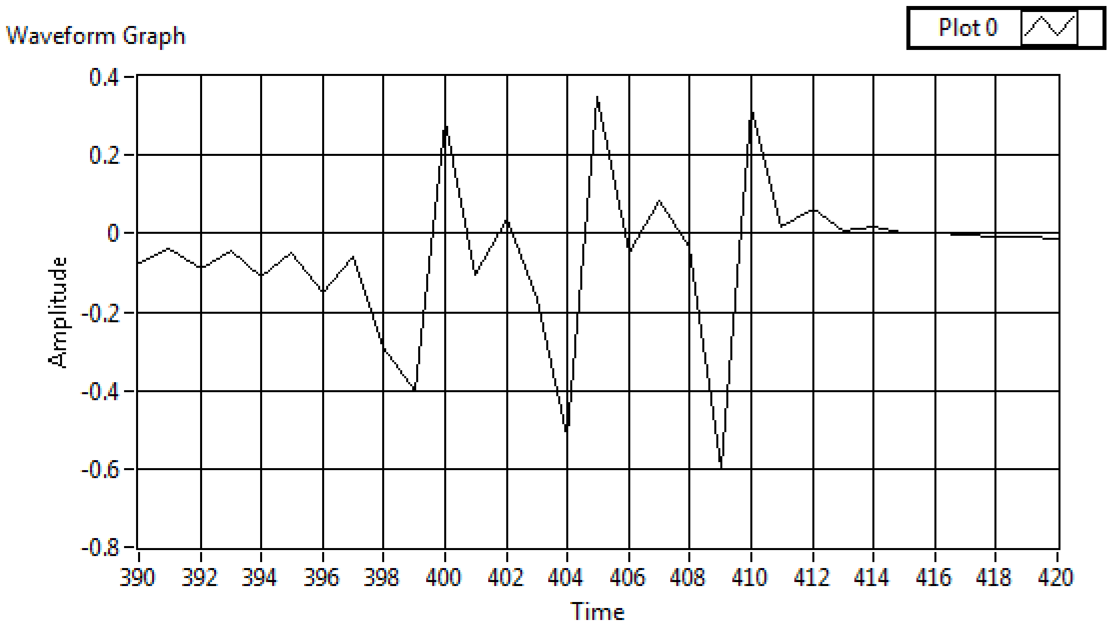

Figure 30: Evaluation of flicker

4.5.5 Harmonics:

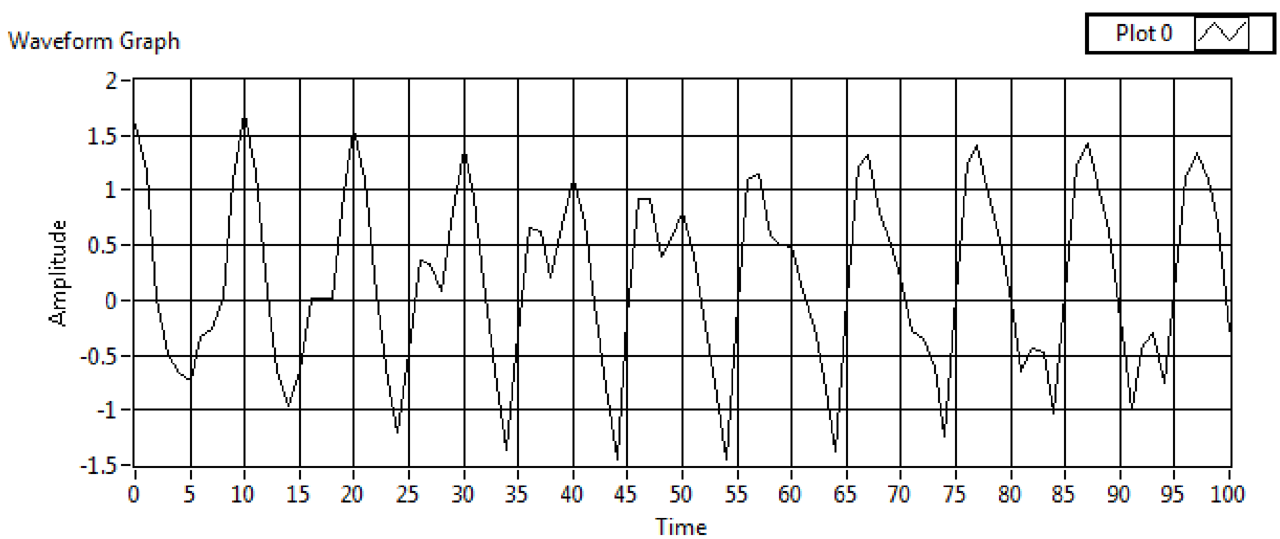

Figure 31: Evaluation of Harmonics

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusion:

The shortcomings in the Hilbert detection and evaluation algorithm has been taken care of by the application of CORDIC algorithm, the algorithm accurately calculates the phase of the error signal at every point, thereby allowing the Hilbert algorithm to detect and evaluate the disturbances accurately. The noise suppression algorithm is a prelogue to phase shifting property of Hilbert Transform which has been employed to detect, classify and evaluate various faults in this project. Disturbances such as voltage swells, voltage sags, voltage fluctuation, harmonics, inter-harmonics, transient oscillation, frequency fluctuation, notch and momentary interruption have been simulated and results have been found to be accurate with respect to detection of the faults, finding out their characteristic magnitudes and time of their occurrence. The method is hence suitable for Real-time application for the detection of faults as the time of occurrence is precisely detected. Using adaptive window width the numerical method is used for exact calculation of harmonics/ interharmonics component. This method adaptively adjusts the window width based on correlation calculation thereby eliminating the unwanted spectral leakage caused by truncation. The iterative algorithm does not require any information about the basic harmonics and the interharmonic constituents of the system. The main parameter required is the signal samples acquired by inspecting the simple indicator at equidistant interim.

5.2 Scope for Future work :

The proposed method of Phase shifting is one of the mediocre manipulations of the transform technique for the detection of the faults. Various manipulations and sheer innovativeness can yield robust techniques better suited for real time application involving various other transforms. Wavelet transforms and fuzzy control offer same efficiency in the detection criteria. More work can be undertaken in employing the same techniques to suitably detect, characterize and filter the disturbances.

The algorithm is suitable for all types of disturbances and gives accurate results without any disparity as it is based purely on the input signals and frequency of the system. But real time execution of the evaluation algorithm may turn out to be a time consuming process. Hence further work can be undertaken in improving the runtime of the algorithm. Inclusion of Wavelet Transform and other means would surely help the algorithm on this level.

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APPENDIX-I

LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
ADPLL	All Digital Phase-Locked Loop
DFT	Discrete Fourier Transform
CORDIC	Coordinate Rotation Digital Computer
FFT	Fast Fourier Transform
HT	Hilbert Transform
DAQ	Data Acquisition Card
SE	Structuring Element
PQ	Power Quality